[Topic: Waterfront Structures](#)

Tuesday June 22nd
12:45 pm - 1:15 pm
.5 PDH

Protect Waterfront Structures Using FRP Pipe Piling

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Technical Sales Manager ~ Waterfront Solutions

Creative Composite Group

Composites
AN INFINITE WORLD OF POSSIBILITIES

FRP Composite Pipe Piling

AGENDA INFO

- Typical Applications
- Manufacturing Process and Materials
- Design Values and Validation
- Standard Details
- Installation Techniques

Marina Guide Piles

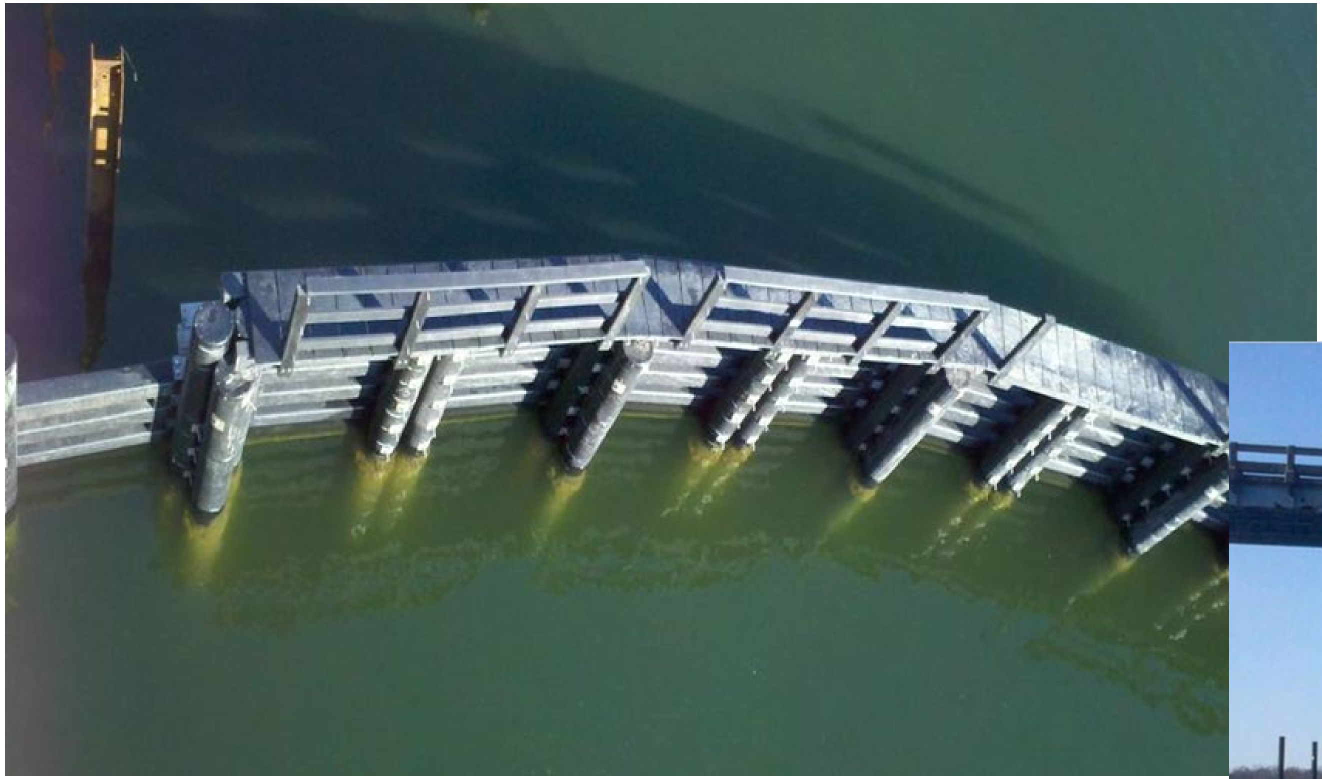
Structural Piles

Fender Piles

Bridge Fender Systems

Floating Dock Piles

Dolphin Piles

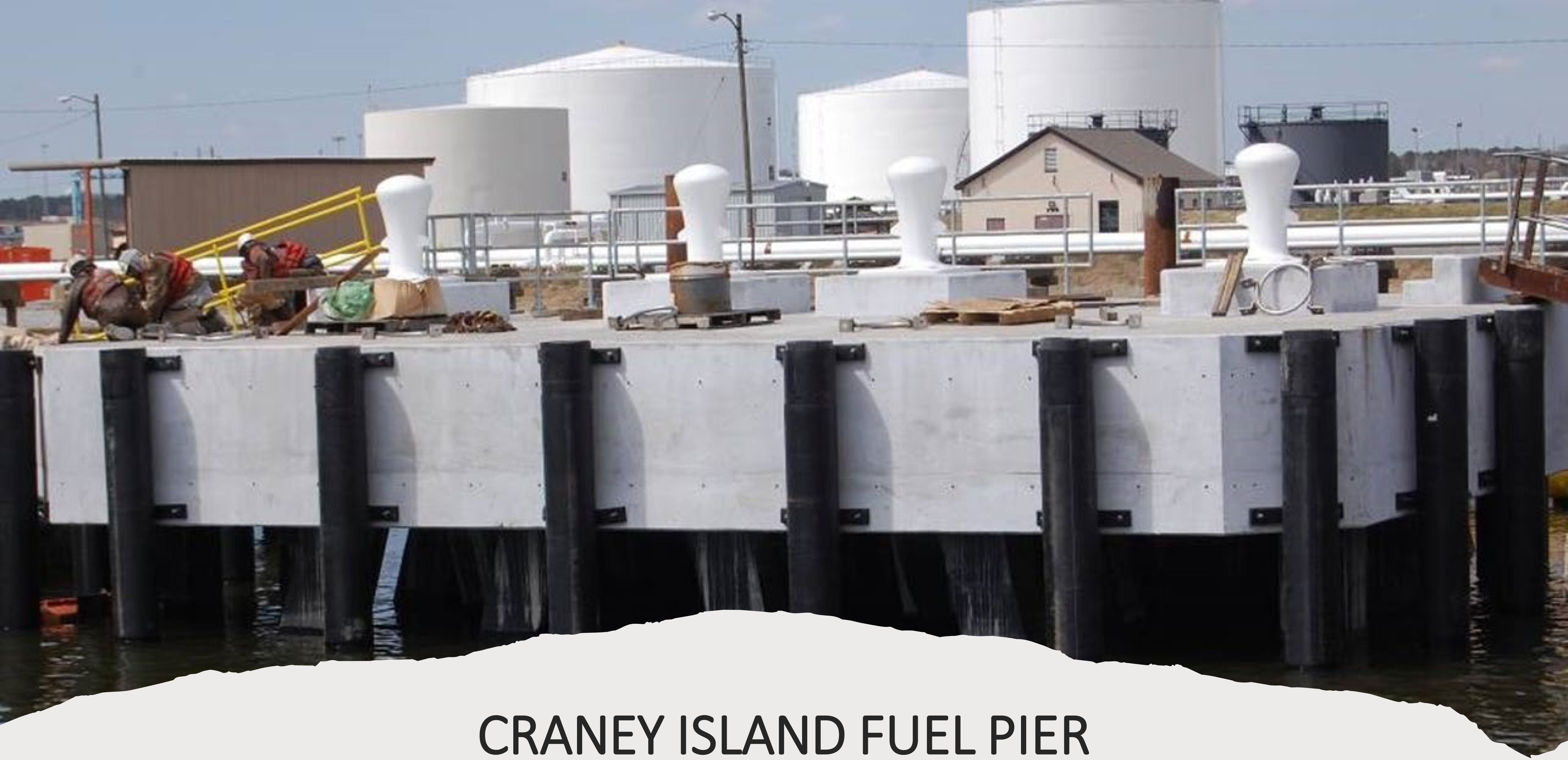


TWIGG BRIDGE ~ VIRGINIA DOT

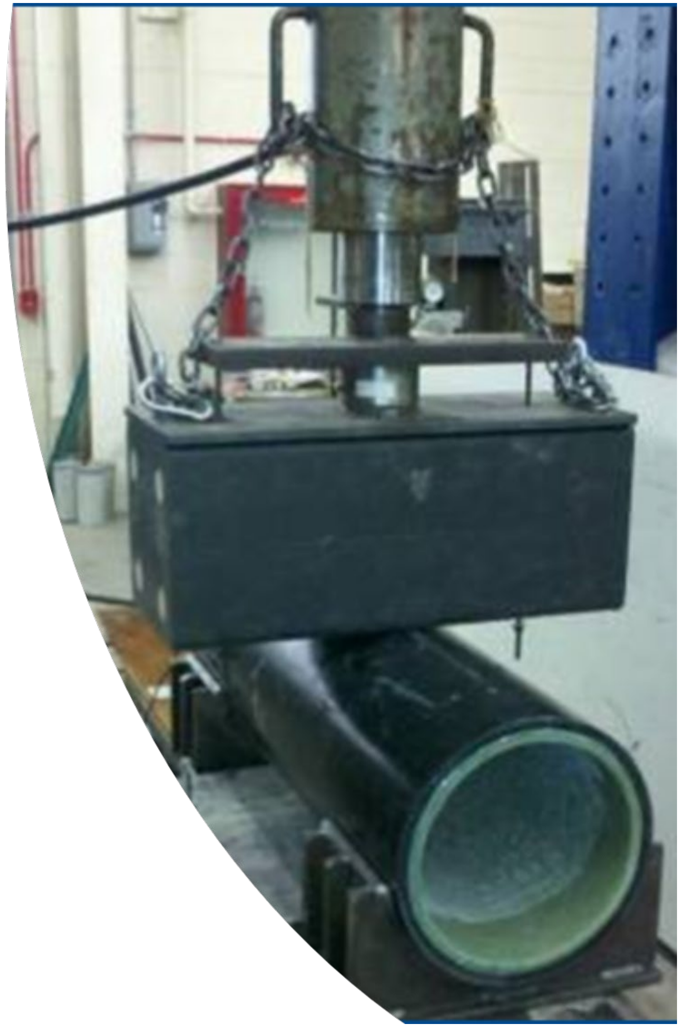
Grassy Sound - NJ

FRP Piles Designed to Act in Composite Action with Concrete Fill

FUEL PIER - USN POINT LOMA



CRANEY ISLAND FUEL PIER



Wharf Charlie – Norfolk, VA

Pier C Ferry Landing ~ NYC

JTA Ferry

Oxy Wingwall ~ Long Beach, CA

DOLPHIN PILES

AMTRAK BRIDGE FENDER NIANTIC RIVER

JACKSONVILLE FIREBOAT PIER

FERRY COVE OYSTER HATCHERY ~
OXFORD, MD

BEARING PILES

MAINE DOT ~ GOODWIN BRIDGE

FLOATING DOCK PILES



DOCK PILES

Fort Anderson, Brunswick, NC

USCG ~ ATON's

Duke Energy Toxaway Bridge ~ Gorges State Park, Sapphire, NC

Boat Lifts

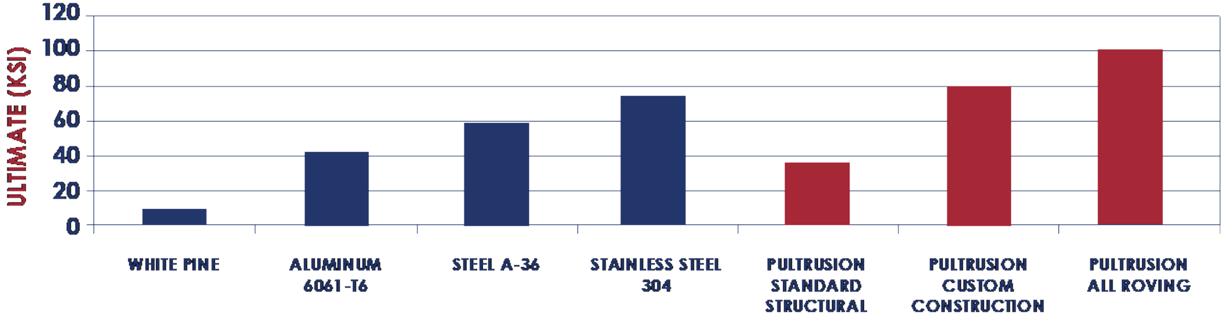
Wilfred Avenue Salamander Crossings ~ Sonoma, CA

The DETAILS ~ Why COMPOSITES?

- **Corrosion Resistance to chemicals and water** — Long Lasting; No Maintenance
- **Unique Combination of Properties** — High strength + low modulus = HIGH ENERGY ABSOPTION
- **Light Weight** — 25% weight of steel; Lighter duty cranes required; More piles per truck
- **Low Sound Transmission**
- **100% Domestic Source Material**
- **Customized Physical Properties**

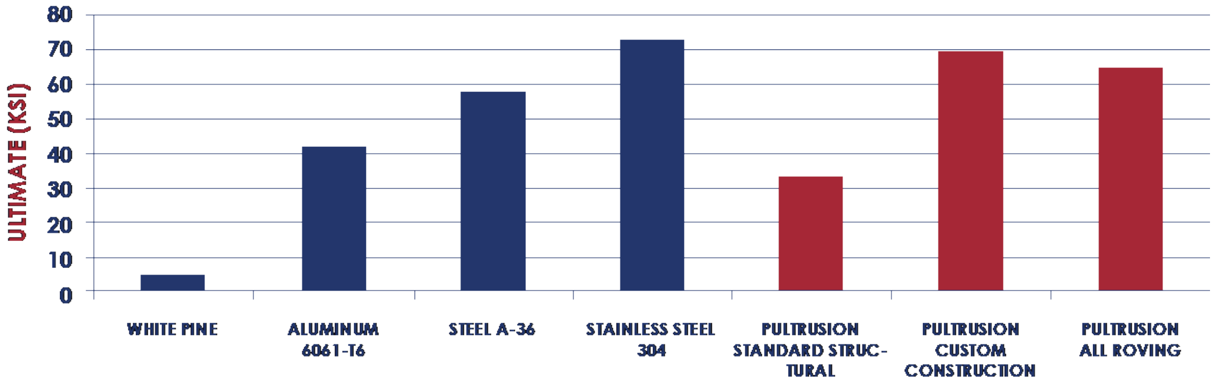
Material Properties, How Do Pultruded Composites Stack Up?

TENSILE STRENGTH



- Superior Tensile Strength/Stronger than A-36 Steel
- Linear Stress/Strain Curve with Little to No Yield

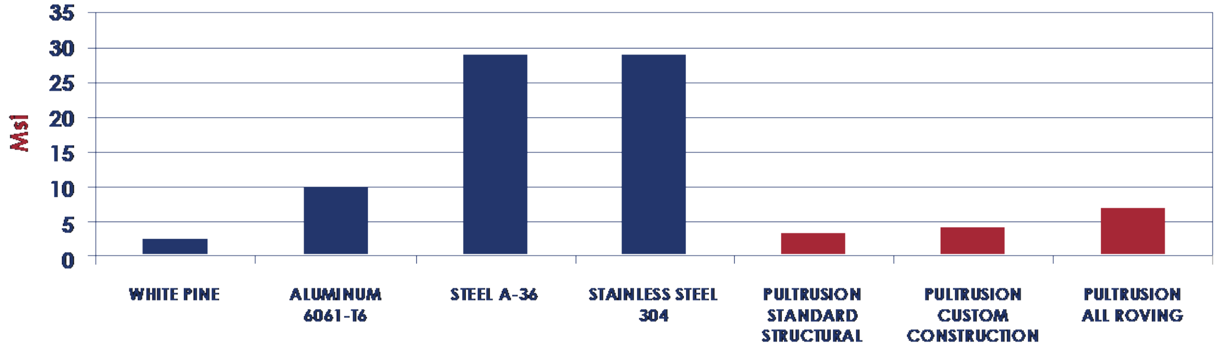
COMPRESSION STRENGTH



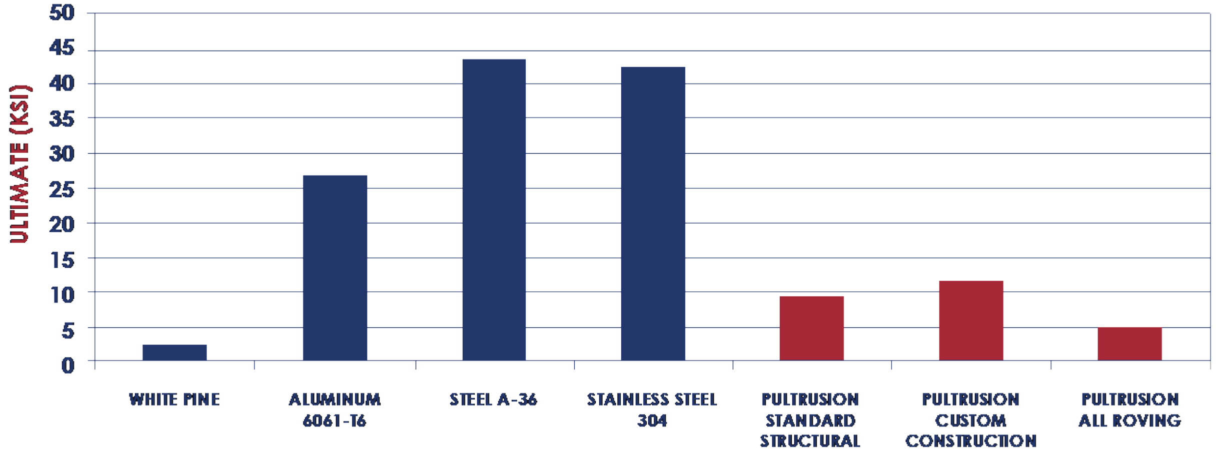
- Superior Compression Strength/Stronger 6061-T6 Aluminum
- Compression Strength and Compression Buckling Normally Govern the Design when Strength Governs

Material Properties, How Do Pultruded Composites Stack Up?

MODULUS OF ELASTICITY

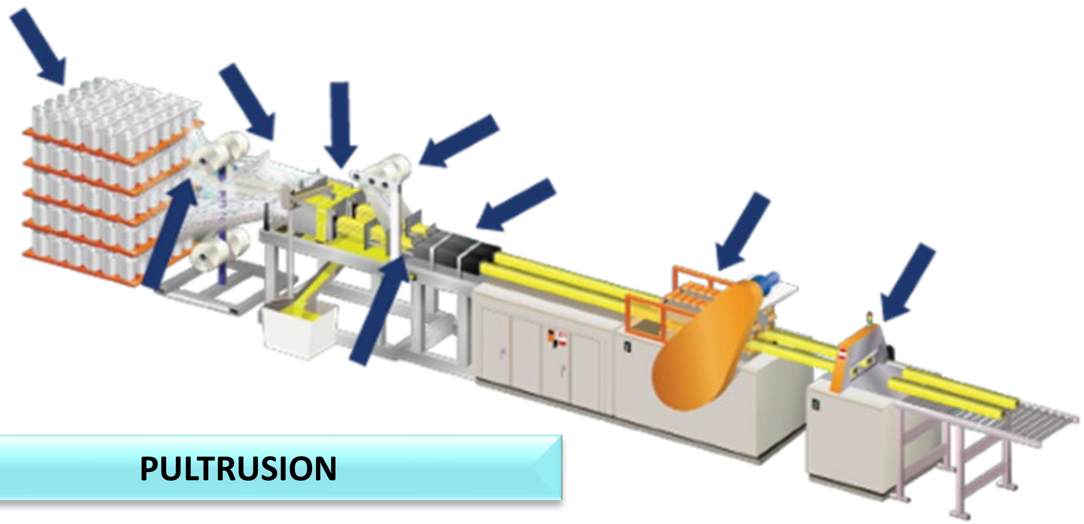


SHEAR STRENGTH



- Lower Shear Strength than Steel and Aluminum
- Lower Shear Modulus than Steel and Aluminum; Serviceability Calculations Should Include Shear Deflection Computations, Especially for Short Spans

FRP PIPE piles Are Manufactured By



PULTRUSION

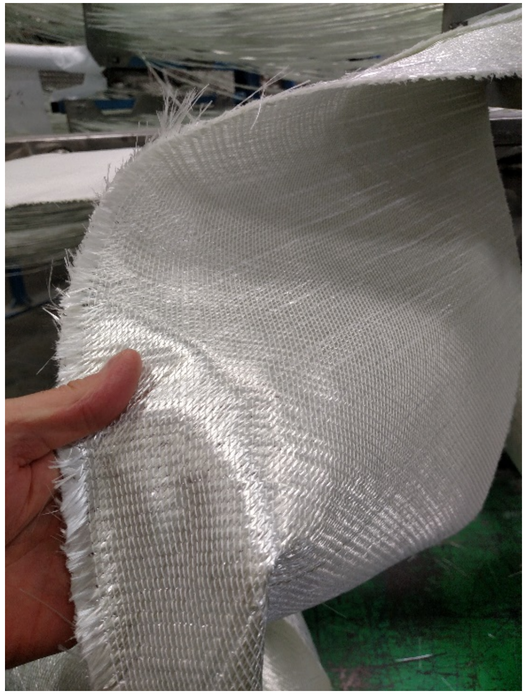
VACCUM INFUSION

FILAMENT WINDING

Fiber Architecture

FRP PIPE Piling is made of E-glass Reinforcements.

Unidirectional roving make up the bulk of the longitudinal properties



Engineered fabrics are stitched unidirectional that form a mat.

The roving are stitched at predetermined angles

Thermoplastic polyester veils are applied to the outer surface for added UV protection

Designing an FRP Pipe Pile structure

FRP Materials can have various
- resin formulations
- fiber types
- fiber orientations and fiber architectures

FRP has a modulus of elasticity of about 1/6th that of steel

FRP materials do not have a traditional yield strength

What is CRITICAL FOR YOUR DESIGN???
- Service Life/Longevity
- Resiliency
- Application(s)

Mechanical Properties					
LRFD Section	Property	ASTM Test	Required Characteristic Value	Characteristic Urethane Resin Test Results	Units
Table 1.3-1	Barcol Hardness	D2583	> 40 w/ COV <10%		
	Glass Transition Temperature	D4065	> 150F w/ COV<10%		
	Coefficient of Thermal Expansion	D696	< 7.5E-6 in/in/F w/ COV<10%		
	Water Absorption	D570 / Proc. 7.4	< 2% w/ COV <10%		
Table 1.3-2(a)	Tensile Strength Lengthwise	D638	30,000	**95,453**	psi
	Tensile Strength Crosswise	D638	7,000	**21,958**	psi
	Tensile Modulus Lengthwise	D638	3.00	**4.90**	Msi
	Tensile Modulus Crosswise	D638	0.80	**1.79**	Msi
	Compressive Strength Lengthwise	D6641	30,000	**74,348**	psi
	Compressive Modulus Lengthwise	D6641	3.00	**3.82**	Msi
	Compressive Modulus Crosswise	D6641	1.00	**2.61**	Msi
	In-Plane Shear Strength	D5379	8,000	**18,660**	psi
	In-Plane Shear Modulus	D5379	0.40	**1.04**	Msi
	Interlaminar Shear	D2344	3,500	**4,529**	psi
	Bearing Stress Lengthwise	D953	21,000	**44,190**	psi
	Bearing Stress Crosswise	D953	18,000	**22,978**	psi
	Pull-through Strength of Fastener	D7332 / Proc.B	18,000		psi
Section 1.3.4	Glass Transition Temperature (Water)	D4065	>15% of Char. Value		
	Tensile Strength Lengthwise (Water)	D638	>15% of Char. Value		psi
	Tensile Strength Crosswise (Water)	D638	>15% of Char. Value		psi
Section 1.3.4	Glass Transition Temperature (UV)	D4065	>15% of Char. Value		
	Tensile Strength Lengthwise (UV)	D638	>15% of Char. Value		psi
	Tensile Strength Crosswise (UV)	D638	>15% of Char. Value		psi
Section 1.3.4	Glass Transition Temperature (Alkali)	D4065	>15% of Char. Value		
	Tensile Strength Lengthwise (Alkali)	D638	>15% of Char. Value		psi

What testing has the Manufacturer performed?

- How have they derived their data?
  - Characteristic Design Values Have Been Developed And Published Per _______?
  - The Capacities Were Developed From Full Section Testing?
  - Failure Load Is Defined As _______?

Characteristic Strengths of Bolted Connections for Forces Applied Parallel to the Pile

Round Polyurethane Piles	Single 5/8" Bolt		Two 5/8" Bolts		Single 3/4" Bolt		Two 3/4" Bolts		Single 1" Bolt		Two 1" Bolts	
TU440 10" x 3/8" (254mmx9.52mm)	6,505	(2,951)	13,010	(5,901)	7,806	(3,541)	15,612	(7,082)	10,408	(4,721)	20,816	(9,442)
TU455 12" x 3/8" (305mmx9.52mm)	4,231	(1,919)	8,462	(3,838)	5,077	(2,303)	10,155	(4,606)	6,770	(3,071)	13,540	(6,142)
TU450 12" x 1/2" (305mmx12.7mm)	7,854	(3,562)	15,708	(7,125)	9,425	(4,275)	18,849	(8,550)	12,566	(5,700)	25,132	(11,400)
TU460 16" x 1/2"(406mmx12.7mm)	6,005	(2,724)	12,011	(5,448)	7,206	(3,269)	14,413	(6,538)	9,609	(4,358)	19,217	(8,717)
Octagonal Vinyl Ester Piles	**Single 5/8" Bolt**		**Two 5/8" Bolts**		**Single 3/4" Bolt**		**Two 3/4" Bolts**		**Single 1" Bolt**		**Two 1" Bolts**	
CP076 8" x .25" (203mmx6.35mm)	2,606	(1,182)	5,212	(2,364)	3,127	(1,419)	6,255	(2,837)	4,170	(1,891)	8,340	(3,783)
CP074 10" x. 25" (254mmx6.35mm)	3,286	(1,490)	6,572	(2,981)	3,943	(1,789)	7,886	(3,577)	5,257	(2,385)	10,515	(4,769)
CP210 10" x. 275" (254mmx6.98mm)	2,212	(1,003)	4,423	(2,006)	2,654	(1,204)	5,308	(2,408)	3,539	(1,605)	7,077	(3,210)


Bolted Connection Test - Parallel

What testing has the Manufacturer performed?

4-point bend test

Shear Testing

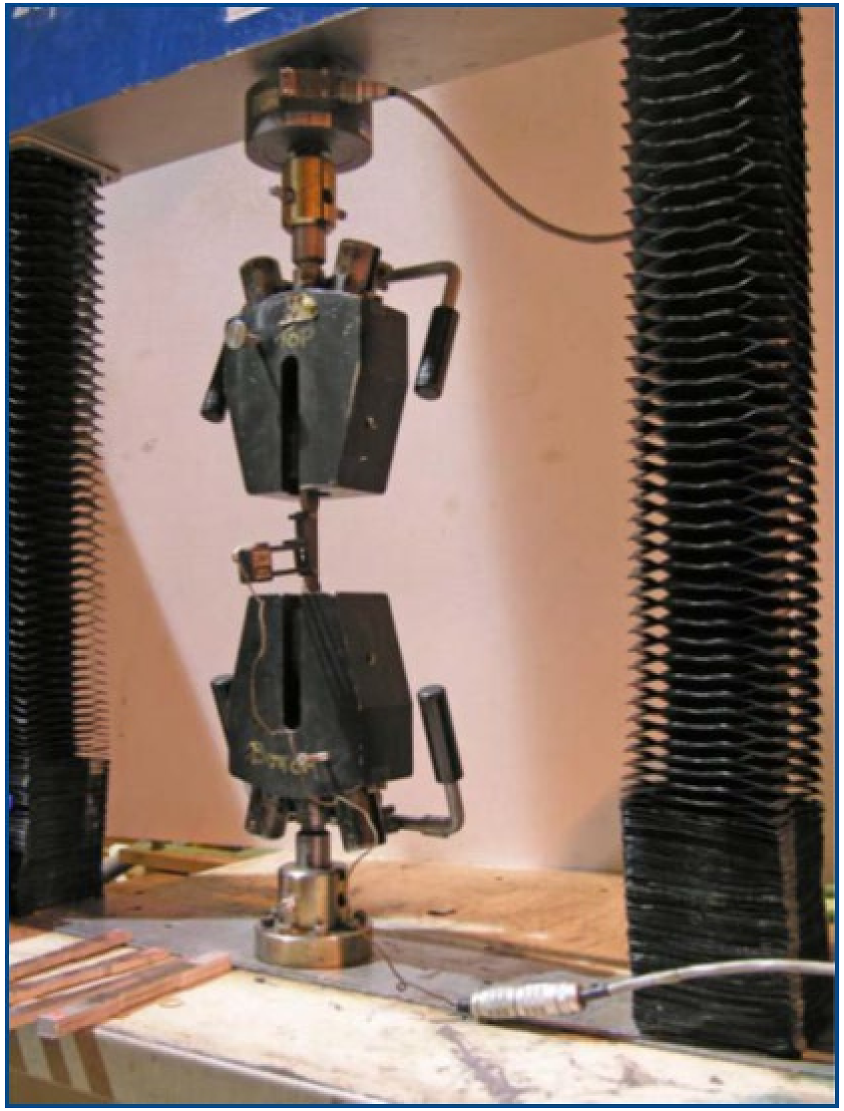
Axial Load Testing

Characteristic Design Strengths Should Be Published per ASTM D7290

ASTM D7290 - 06(2017)

Standard Practice for Evaluating Material Property Characteristic Values for Polymeric Composites for Civil Engineering Structural Applications

Active Standard ASTM D7290 | Developed by Subcommittee: D30.10



Why ASTM D7290?

It is an internationally recognized standard for evaluating material property characteristic values for polymeric composites for civil engineering structural applications.

The characteristic value is a statistically-based material property representing the 80% lower confidence bound on the 5th-percentile value of a specified population.

Writing a Spec.

ASTM D7290 derived design strengths should be specified.

Can be used for ASD or LRFD design basis.

SUPERPILE® Mechanical Properties	Round FRP Pipe Pile TU440 Polyester 10"x3/8" Metric (254mm x 9.52m)		Round FRP Pipe Pile TU455 Polyurethane 12"x3/8" Metric (305mm x 9.52mm)		Round FRP Pipe Pile TU450 Polyurethane 12"x1/2" Metric (305mm x 12.7mm)		Round FRP Pipe Pile TU460 Polyurethane 16"x1/2" Metric (406mm x 12.7mm)	
Average Flexural Strength per ASTM D6109 psi (Mpa)	65,722[3]	(453)[3]	52,000	(359)	69,658	(480)	57,270	(395)
Characteristic Flexural Strength per ASTM D6109 psi (Mpa)	*****	*****	*****	*****	56,111	(387)	49,840	(344)
Average Compression Strength per ASTM D6109 psi (Mpa)	65,722[3]	(453)[3]	52,000	(359)	69,658	(480)	57,270	(395)
Characteristic Compression Strength per ASTM D6109 psi (Mpa)	*****	*****	*****	*****	56,111	(387)	49,840	(344)
Average In-Plane Shear Strength psi (Mpa)	10,792	(74)	15,605	(108)	16,039	(111)	17,170	(118)
Characteristic In-Plane Shear Strength psi (Mpa)	9,456	(65)	13,212	(91)	13,713	(95)	14,936	(103)
Average Shear Capacity lbs (Kg)	61,185	(27,753)	106,894	(48,486)	145,153	(65,840)	208,616	(94,626)
Characteristic Shear Capacity lbs (Kg)	53,611	(24,317)	90,502	(41,051)	124,103	(56,292)	181,472	(82,314)
Average Torque Strength lb-ft (kN•m)	49,076	(67)	103,519	(140)	138,829	(188)	269,987	(366)
Characteristic Torque Strength lb-ft (kN•m)	43,001	(58)	87,644	(119)	118,696	(161)	234,859	(318)
Average Axial Compression Strength psi (Mpa)	65,722	(453)	52,000	(359)	69,658	(480)	57,270	(395)
Characteristic Axial Compression Strength psi (Mpa)	*****	*****	*****	*****	56,111	(387)	49,840	(344)
Average Axial Compression Capacity (Short Column) lb (kg)	745,222	(338,027)	712,400	(323,139)	1,260,810	(571,894)	1,391,661	(631,247)
Characteristic Axial Compression Capacity (Short Column) lb (kg)	*****	*****	*****	*****	1,015,609	(460,673)	1,211,112	(549,351)
Average Modulus of Elasticity per ASTM D6109 psi (Gpa)	6.31E+06[4]	(43.5)[4]	5.26E+06	(36.3)	5.91E+06	(40.7)	5.99E+06	(41.3)
Bending Stiffness (EI) per ASTM D6109 lbs•in² (kg•mm²)	8.30E+08[4]	(2.43E+11)[4]	1.22E+09	(3.57E+11)	1.77E+09	(5.17E+11)	4.38E+09	(1.28E+12)
Average Moment Capacity per ASTM D6109 kip-ft (kN•m)	144[3]	(195)[3]	167	(227)	289	(392)	437	(592)

SUPERPILE® Mechanical Properties	Round FRP Pipe Pile TU440 Polyester 10"x3/8" Metric (254mm x 9.52mm)		Round FRP Pipe Pile TU455 Polyurethane 12"x3/8" Metric (305mm x 9.52mm)		Round FRP Pipe Pile TU450 Polyurethane 12"x1/2" Metric (305mm x 12.7mm)		Round FRP Pipe Pile TU460 Polyurethane 16"x1/2" Metric (406mm x1 2.7mm)	
Characteristic Moment Capacity per ASTM D6109 kip-ft (kN•m)	*****	*****	*****	*****	233	(316)	380	(515)
Average Energy Absorption kip-in (kN•m)	*****	*****	341	(39)	643	(73)	829	(94)
Characteristic Energy Absorption kip-in (kN•m)	*****	*****	*****	*****	405	(46)	603	(68)
Average Pin Bearing Strength Crosswise psi (Mpa)	19,155	(132)	19,823	(137)	21,676	(149)	23,666	(163)
Characteristic Pin Bearing Strength Crosswise psi (Mpa)	16,577	(114)	12,447	(86)	12,546	(87)	20,771	(143)
Average Pin Bearing Strength Lengthwise psi (Mpa)	31,824	(219)	30,793	(212)	30,149	(208)	27,788	(192)
Characteristic Pin Bearing Strength Lengthwise psi (Mpa)	27,755	(191)	18,053	(125)	25,132	(173)	19,217	(133)
Average Pile Crush Strength lb (kg) (based on a 9" wide load path)[1]	*****	*****	10,600	(4,808)	17,970	(8,151)	16,600	(7,530)
Characteristic Pile Crush Strength lb (kg) (based on a 9" wide load path)[1]	*****	*****	8,060	(3,656)	13,782	(6,251)	11,667	(5,292)
Average Crush Strength, with FRP Insert, lb (kg) (based on a 9" wide load path)[1]	*****	*****	*****	*****	73,780	(33,466)	44,213	(20,055)
Characteristic Crush Strength, with FRP Insert, lb (kg) (based on a 9" wide load path)[1,2]	*****	*****	*****	*****	51,370	(23,301)	*****	*****

Moment capacity derived via the LRFD Manual of Pultruded Fiber Reinforced Polymer Structures

Note that the average modulus of elasticity values should be used for serviceability calculations

Engineering details

- Hollow Composite Pipe Piles Require Attention To The Connection Details.
  - Design Connection Details to Decrease the Point Load Stress

- Excessive Point Loads Should Be Avoided.

- Attention to Bolt Holes ~ Pin Bearing.

Engineering details

- Long Column Loading, Follows Euler Buckling

- At an unsupported length of 8’, a 10” diameter x 3/8” wall FRP pile

  has an ultimate load capacity of 627,864 lbf

$$F_{cr} = \sigma_c - 1/7\frac{KL}{r}$$

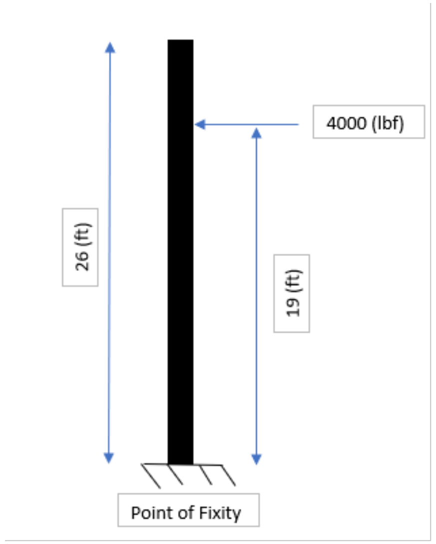
Where:
F_{cr} = Critical compression stress
= Axial compression strength
K = Effective length factor
L = Laterally unbraced length of member
r = Radius of gyration about the axis of buckling

$$F_{cr} = \frac{\pi^2 E}{\left(\frac{KL}{r}\right)^2}$$

Where:
F_{cr} = Critical compression stress
E = Modulus of elasticity
K = Effective length factor
L = Laterally unbraced length of member
r = Radius of gyration about the axis of buckling

We typically recommend a 3x Factor of Safety be applied to the ultimate capacity.

This is assuming an effective length coefficient K=1 (pinned-pinned end conditions).

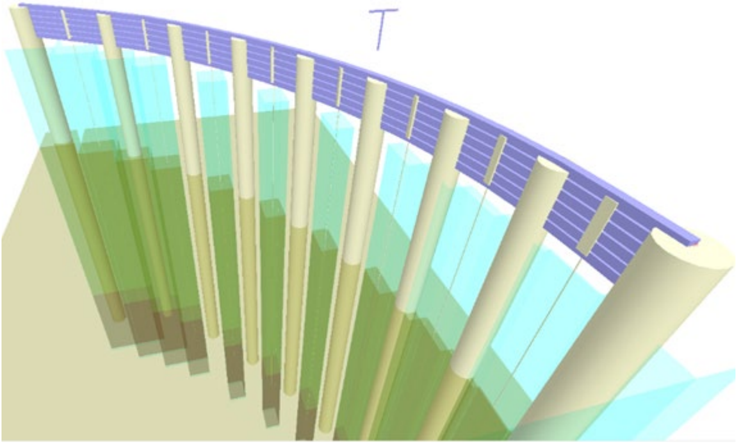


Pile	MOI (in^4)	MOE (psi)	EI (lbs*in^2)
Steel (10 x 3/8)	132	2.90E+07	3.81E+09
Steel (12 x 1/2)	299	2.90E+07	8.68E+09
FRP (10 x 3/8)	132	6.31E+06	8.30E+08
FRP (12 x 1/2)	299	5.91E+06	1.77E+09
FRP (16 x 1/2)	732	5.99E+06	4.38E+09
FRP (10 x 3/8) w/ Concrete			2.13E+09
FRP (12 x 1/2) w/ Concrete			4.36E+09
FRP (16x1/2) w/ Concrete			1.33E+10
*deflection taken at top of pole; 4000 load applied 7ft from top			
*cantilever length = 26ft			

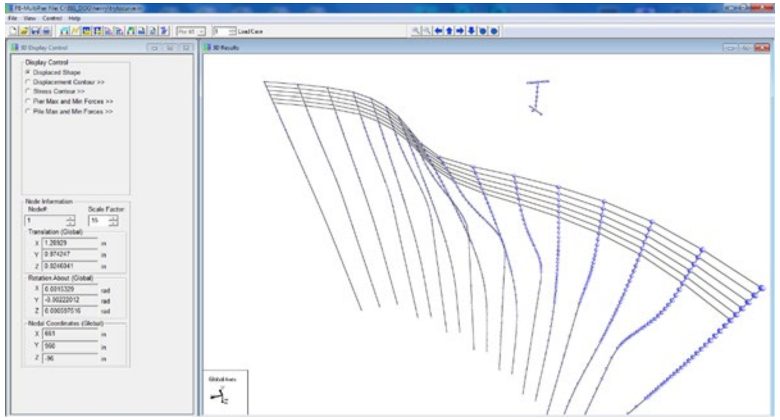
Engineering a Fender System

- Why do composites make sense for a Fender System?

- Depending upon the final use, various Modeling software is readily available
- The soil resistance and strain energy of the fender system is analyzed.
- The fender system geometric layout is optimized based on the permissible deflection of the system.
- The energy is derived by the application of a static load applied to the non-linear three-dimensional soil pile model.
- Minimum pile tip elevations are determined such that the moment capacity of the pile can be reached before soil failure.

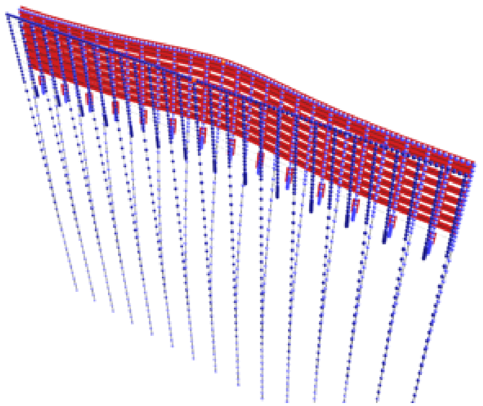


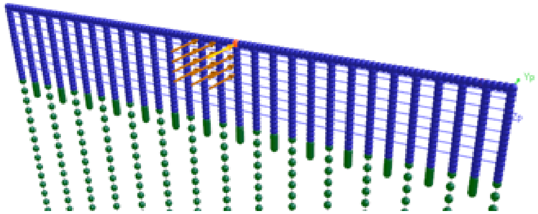
FB-MultiPier v4.19.3



Why is FRP better than Steel?

FRP Pile (36FP150)

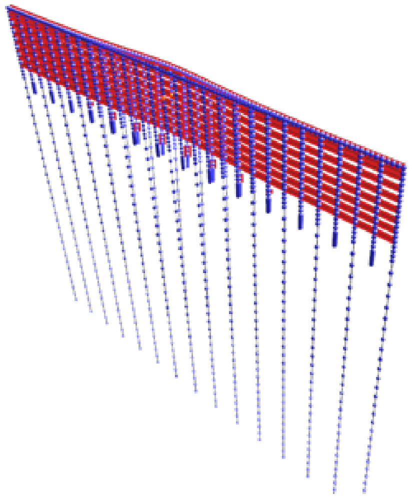


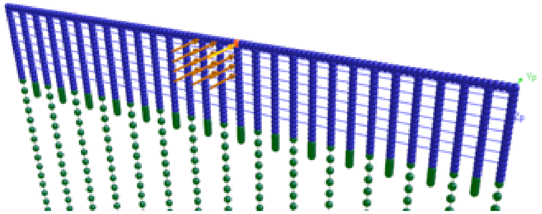


	FiberPILE (36FP150)	Steel Pile (36" x 1.5")
Static Load	684 kip	684 kip
Displacement @ Load	113.6 in	29 in
Displacement @ Ends	42.7 in	4.5 in
Energy Absorbed	3,006 ft-kip	684 ft-kip
Maximum Pile Moment	3,760 ft-kip	5,703 ft-kip
Pile Moment Capacity	6,518 ft-kip	5,048 ft-kip*

FiberPILE system absorbs 4.4x the amount of energy of the system with a significant decrease in the pile moment.

Steel Pile (36" x 1.5")

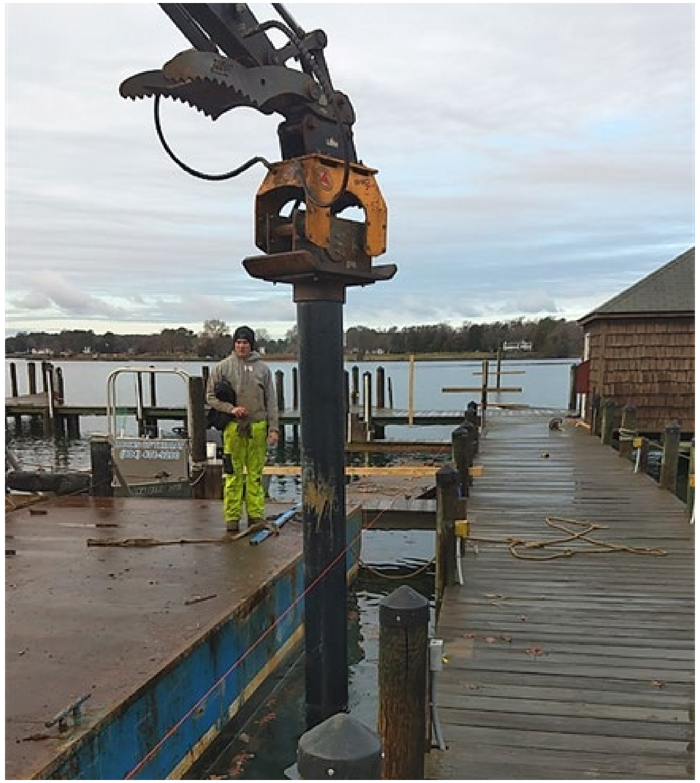




*Based on ASTM A252 Grade 3 Yield Strength 45 ksi

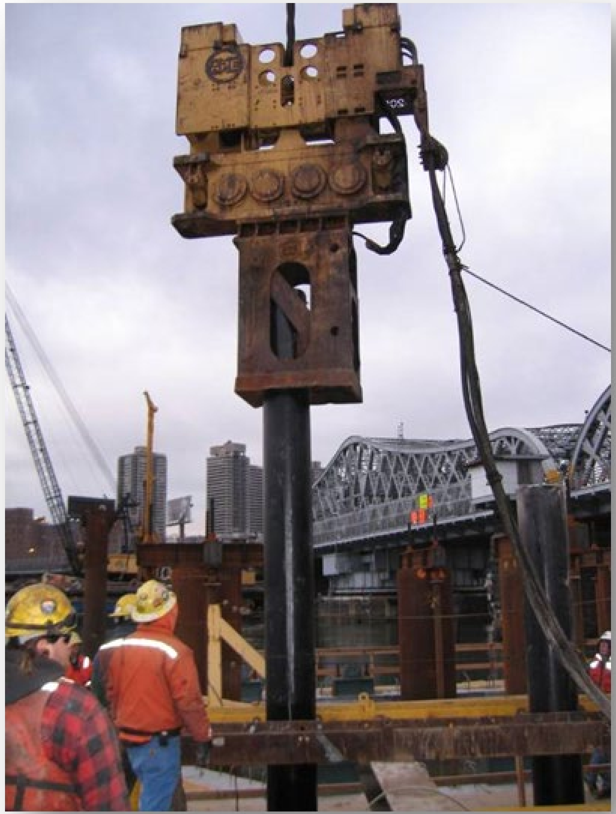

NO TRESPASSING
NORFOLK

Installation



Contractors typically drive with a male or female insert which aids in installation.

Installation



Piles are efficiently driven using industry standard driving equipment including diesel, vibratory and drop-end hammers.

Installation

Can you Splice FRP Piles?

Fiberglass Reinforced Filament Wound splices were utilized in areas with low overhead clearance, powerlines, etc.

Ravenswood Bridge, Dania Beach, FL

INSTALLATION Acoustics

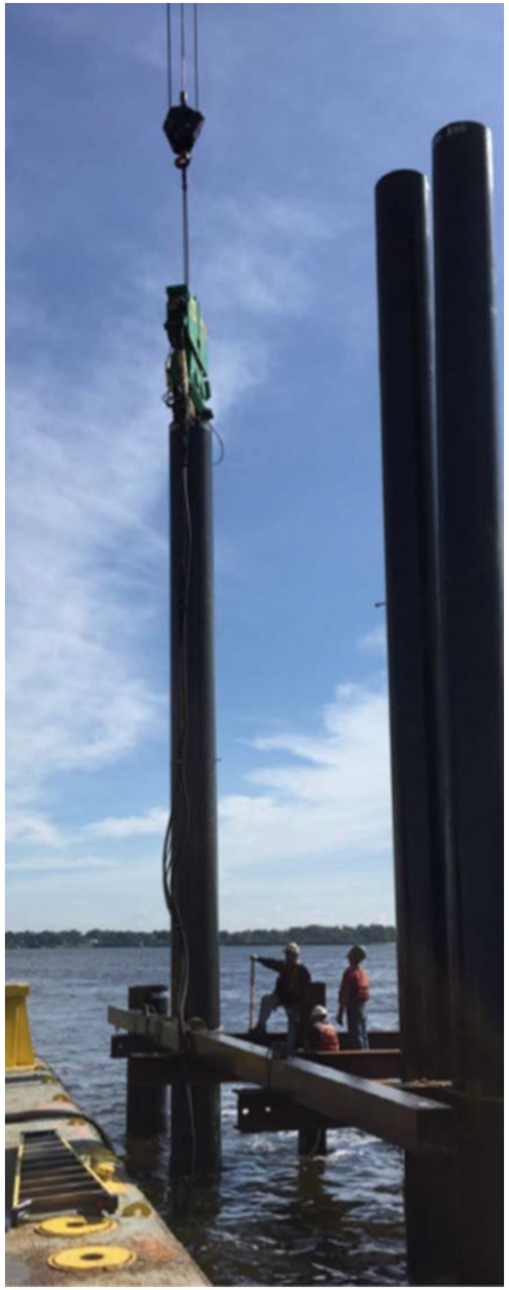
More focus on reducing installation Acoustics

Driving acoustics often restrict the construction calendar

Not an issue with FRP piles

Testing in the James River indicated ~ Peak sound levels did not exceed the background sound pressure levels

Maximum peak sound pressure level was significantly lower than the Calif Fisheries (FWGP) threshold



Concluding Points

- Safety factors of 2.5 are recommended for members in bending and 3.0 for shear
- FRP pipe piles are corrosion resistant, offer longevity and typically drive as 2x fast as solid piles
- Engineers should specify material design properties based on ASTM D7290
- PDA analysis suggests that 16" FRP piles have a driving resistance of up to 350 kips
- Stiffer soils will more than likely require a cutting shoe or driving tip
- Always specify the manufactures recommended hardware to avoid stress risers
- Caps and connecters are common and offered by most manufacturers
- Consult with the manufacturer for proper design values, construction details and installation techniques – Not all FRP pipe piles are the same!

Thank You!

Questions?

Topic: Waterfront Structures
Protect Waterfront Structures Using FRP Pipe Piling
Tuesday June 22nd
12:45 pm - 1:15 pm
.5 PDH

Presenter: Corey Sechler
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Composites
AN INFINITE WORLD OF POSSIBILITIES